Influence of LHDI on Magnetic Reconnection: The role of the lower-hybrid drift instability (LHDI) in reconnection has been a subject of considerable debate since the early 1970s with ideas ranging from source of anomalous resistivity to enhancement of the tearing mode through generation of electron temperature anisotropy. However, the required 3D full particle simulations have been out of reach until very recently. Using the largest kinetic simulations to date, we have been able to perform 3D full particle simulations at high mass ratio to examine the evolution of the LHDI and its effect on reconnection. In order to reach closure, we are using boundary and initial conditions relevant to both the magnetopause and the Magnetic Reconnection experiment (MRX) at Princeton where the properties of these waves are being studied in a controlled setting. Our 3D simulations demonstrate the instability gives rise to a vigorous kinking of the electron layer, with a real frequency in the lower-hybrid range. It appears that the density gradients near the reconnection layer play a crucial role in driving and maintaining this instability, since the amplitudes are larger for asymmetric layers that maintain strong gradients. This result is important, since both the magnetopause and the MRX device have intrinsic gradients that tend to maintain this instability at a vigorous level that may substantially influence the reconnection process. The basic features of this instability are illustrated below for the two types of setups: (1) experimental boundary conditions relevant to MRX [*Dorfman et al.,* 2008; *Roytershteyn et al.,* 2010b] (left panels) and (2) a collisionless open boundary setup with an asymmetric initial condition relevant to the magnetopause (right panels). We are working to compare these simulations with both MRX measurements and space observations in order to better understand the influence of this instability on reconnection.

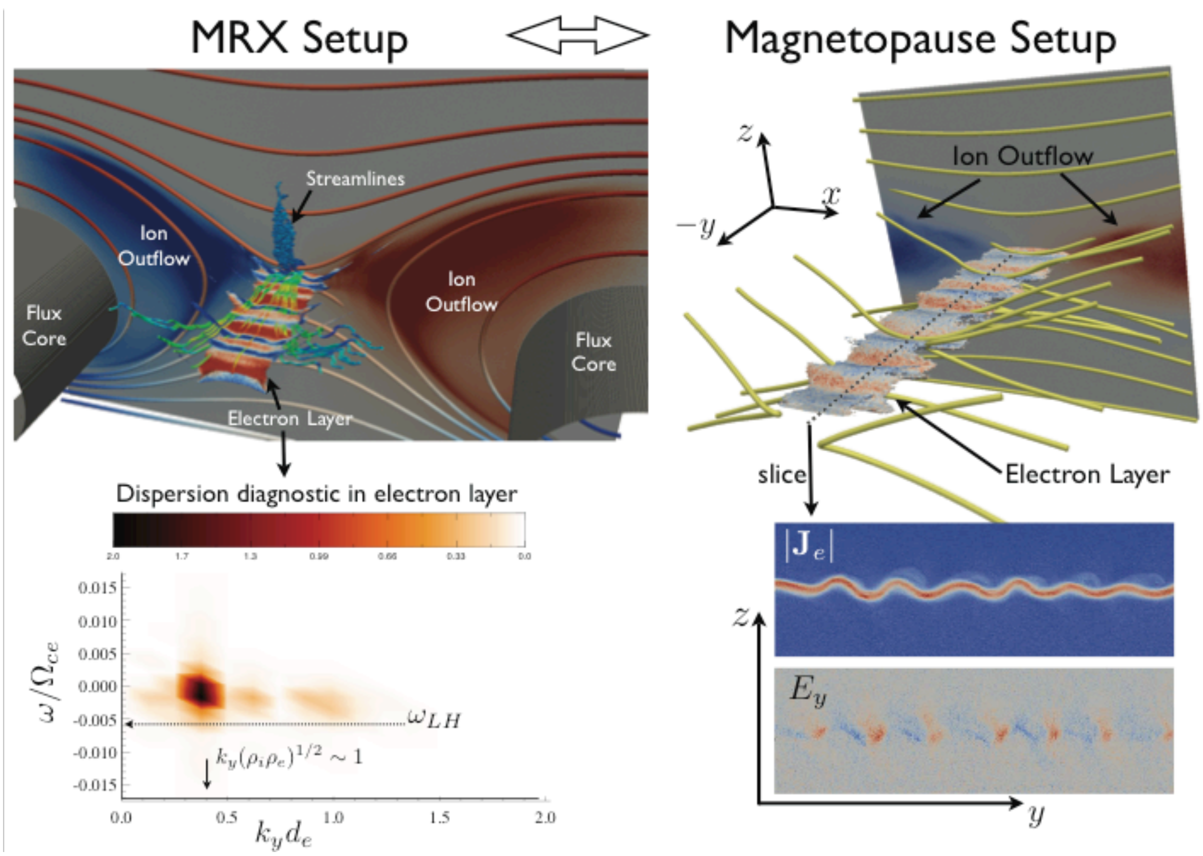

Figure 1. Fully kinetic 3D simulations of the lower-hybrid drift instability at high mass ratiomi/me=300 for MRX geometry (left) and open BC magnetopause setup (right).

Formation of Flux Ropes in 3D Reconnection: The formation mechanism of flux transfer events (FTEs) remains a subject of considerable controversy. Using global MHD simulations, some authors have concluded that a dipole tilt is required for the formation of FTEs, whereas others have observed FTEs in the absence of dipole tilt and have attributed the formation to a flow instability at the subsolar point, which generates a vortex that in turn creates a flux rope. Given the well-known issues with the MHD description of collisionless reconnection, we have taken a different approach to this problem. We have used local 3D fully kinetic simulations of reconnection and 3D global hybrid simulations of the magnetosphere to examine FTE formation at the dayside magnetopause. Our results suggest that elongation of the diffusion region that we had first reported in 2D local simulations remains robust in 3D and is the main mechanism for formation of FTEs. There are, however, significant differences in the details and structure of FTEs in 3D as compared to 2D. In real 3D systems, both primary and secondary magnetic islands correspond to extended flux ropes, which can interact in a variety of complex ways not possible in 2D. We are exploring these questions using a combination of Vlasov theory and 3D petascale kinetic simulations running on the largest available supercomputers. These unprecedented simulations, using up to ~1.3 trillion particles, have revealed an inherently 3D evolution featuring the formation and interaction of flux ropes within the initial current layer, followed by the subsequent generation of secondary flux ropes within the elongated current sheets extending outward from the diffusion region as well as along the separatrices. These results may have far-reaching implications for a range of issues, including the structure of the exhaust, the dissipation rate, the generation of stochastic magnetic fields and particle transport.

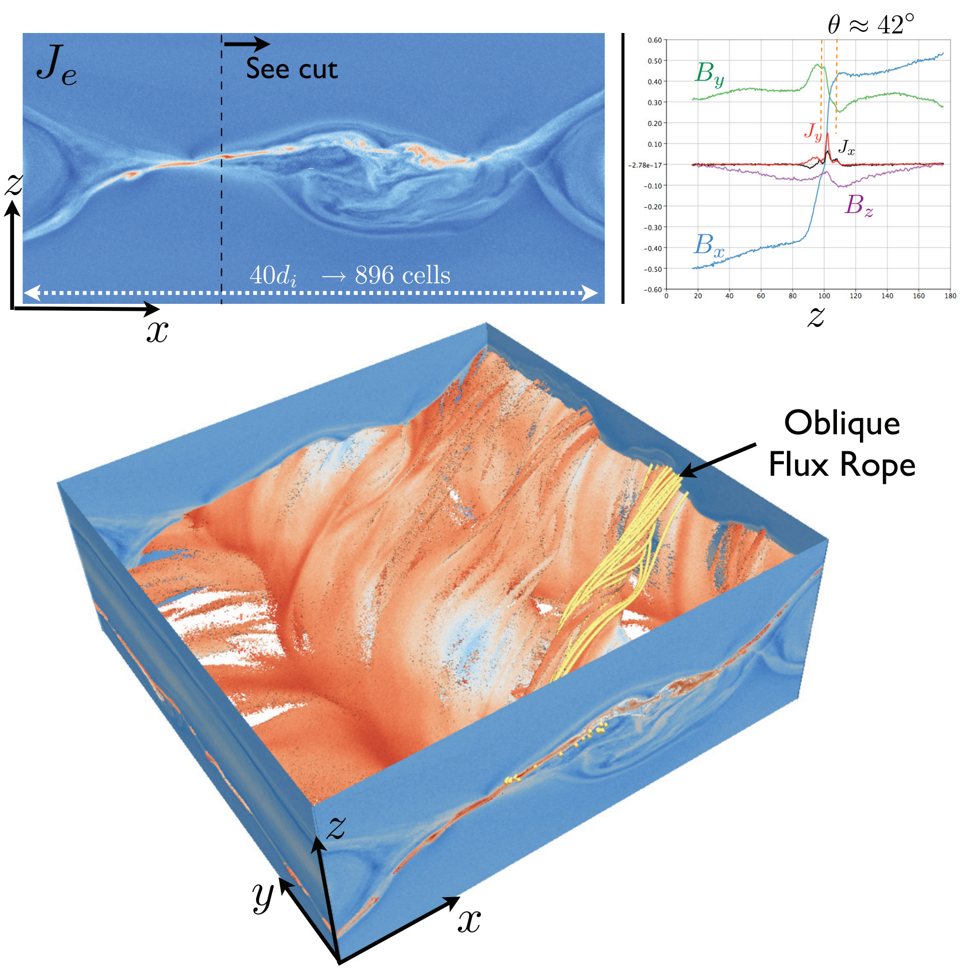

Figure 2. Fully kinetic 3D simulations of guide field reconnection, showing the formation of an oblique flux rope associated with the elongated electron-scale layer along the separatrix.

Figure 3 shows an example of FTE in a 3D global hybrid simulation. One of the interesting features is the generation of vortex flow due to the passage of FTE. Similar features have also been reported in spacecraft data. By tracking the FTE, we have determined that the vortex flow is caused by the FTE rather than being its cause as had been previously suggested by MHD simulations.

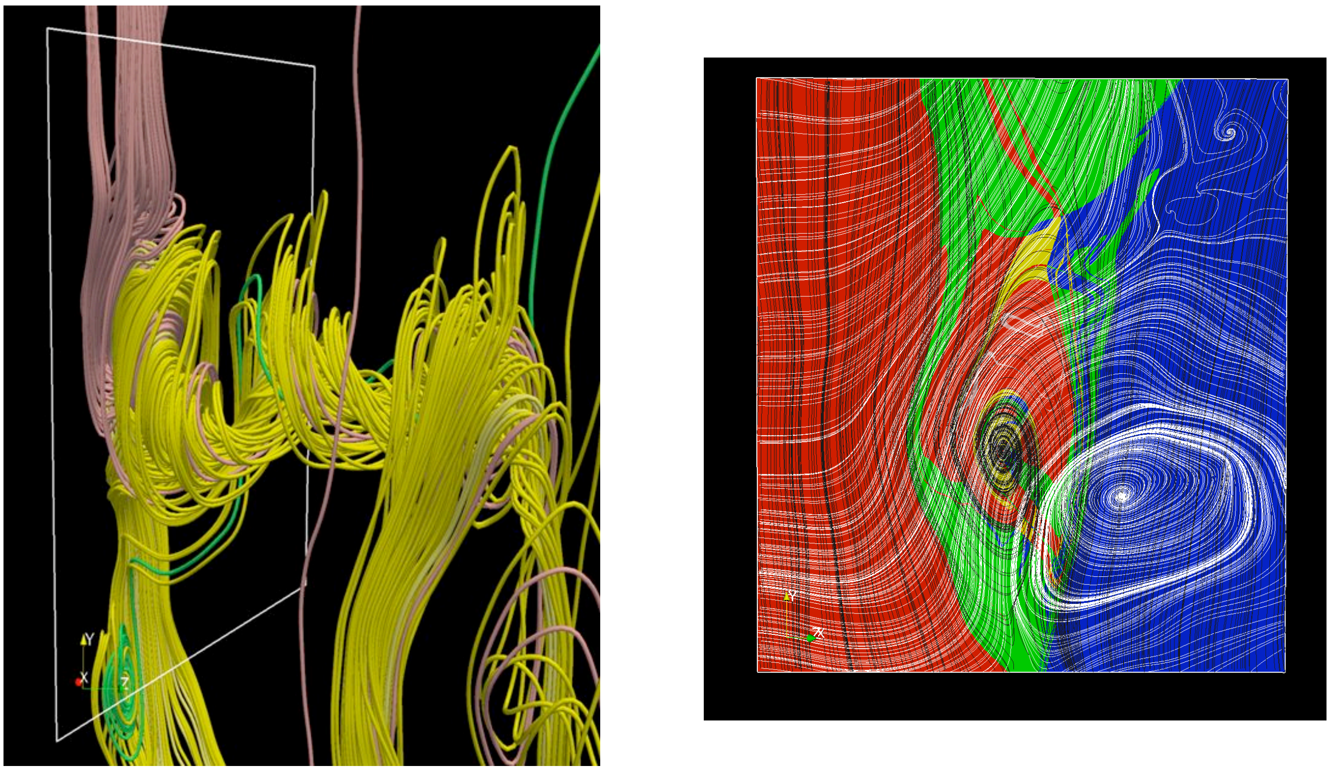

Figure 3 – 3D hybrid simulation results showing the formation of vortex flow associated with a flux rope (FTE) at the dayside magnetopause.